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Synergistic interactions between temporal coupling of complex light and magnetic pulses upon melanoma cell proliferation and planarian regeneration

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ABSTRACT

Synergisms between a physiologically patterned magnetic field that is known to enhance planarian growth and suppress proliferation of malignant cells in culture and three light emitting diode (LED) generated visible wavelengths (blue, green, red) upon planarian regeneration and melanoma cell numbers were discerned. Five days of hourly exposures to either a physiologically patterned (2.5–5.0 μT) magnetic field, one of three wavelengths (3 kLux) or both treatments simultaneously indicated that red light (680 nm), blue light (470 nm) or the magnetic field significantly facilitated regeneration of planarian compared to sham field exposed planarian. Presentation of both light and magnetic field conditions enhanced the effect. Whereas the blue and red light diminished the growth of malignant (melanoma) cells, the effect was not as large as that produced by the magnetic field. Only the paired presentation of the blue light and magnetic field enhanced the suppression. On the other hand, the changes following green light (540 nm) exposure did not differ from the control condition and green light presented with the magnetic field eliminated its effects for both the planarian and melanoma cells. These results indicate specific colors affect positive adaptation that is similar to weak, physiologically patterned frequency modulated (8–24 Hz) magnetic fields and that the two forms of energy can synergistically summate or cancel.

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Planarian; LEDs; melanoma cells; weak magnetic fields; light-magnetic field synergism; red light; green light; blue light

1. Introduction

Light from the sun has been considered to be the singular contribution to the formation of the chemistry that contributed to the formation of living systems (Persinger, 2016; Oparin, 1965). According to Wein's law that relates the temperature of a star to its peak wavelength the Sun's central electromagnetic frequency is about 550 nm with a range distributed over what is considered the visible band (400–800 nm). The boundaries are not exact. Although the intensity of light has been known for centuries to affect the behavior of biological systems and is coupled to season and latitude, the influence of specific wavelengths upon biological responses has been pursued only recently following the development of light emitting diodes (LEDs). On the other hand physiologically-patterned, weak magnetic fields with much less absolute energy can also affect biological systems. Interaction and synergism between light and weak biofrequency-relevant magnetic fields were shown decades ago by Olcese and Reuss (1986) for rats during a discriminatory task. The presence of a weak (1 lux) red light enhanced the animals' capacities to discern the presence or absence of an extremely low frequency magnetic field. In the present experiments, we examined the single and interactive effects of a known bioeffective, physiologically-patterned magnetic field and three specific visible wavelengths either separately or simultaneously upon the growth of planarian and malignant cell cultures.

The brilliant work of Popp (1979) rejuvenated the importance of photons and virtual photons from solar origin as central to living systems. The regulatory aspects of low photon emission for cell-to-cell communication and influence have been considered by Trushin (2004), Fels (2009) and Van Wijk and Schamhart (1988). The potency of the effects generated a compelling question. If cells employ endogenous photon transmissions for regulating signaling pathways across the visible spectra as measured by Dotta et al. (2014), then application of specific wavelengths should be able to facilitate or inhibit similar pathways. The process would be analogous to employing pharmacological agents to simulate, enhance or inhibit endogenous ligands for receptor substrates. There is multiple evidence of the validity of this approach.

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Eells et al. (2004) showed that signal transduction accelerated retinal and wound healing when 670 nm light was applied. Masoumipoor et al. (2013) demonstrated that low level 660 nm laser therapy attenuated neuropathic pain. Wu and Persinger (2011) showed that only 1 mW m^{-2} of 880 nm wavelength LED light increased mobility and stem cell proliferation rates in amputated planarian. Post-ischemic neurite growth with brief 710 nm LED treatment was shown by Choi et al. (2012) to be associated with enhancement of the Mitogen-activated protein kinases (MAPK) pathways.

Most if not all of the changes in cells and organisms that have been reported for specific wavelengths of light have also been elicited by physiologically-patterned, weak magnetic fields. Physiologically-patterned refers to temporal configurations of magnetic fields that are similar to those generated by living systems. Martin et al. (2004) showed that analgesic effects from whole body 30 min exposures of rats to two specific patterns within intensities between 1 and 5 μT were equivalent to the effects of 4 mg per kg of morphine. The transphyla effectiveness of the analgesia was shown for planaria (Murugan and Persinger, 2014), snails (Kavaliers and Ossenkopp, 1991) and human beings (Baker-Price and Persinger, 2003). That the specific magnetic fields were affecting specific receptor subtypes were indicated by the abolishment of the patterned magnetic field-induced analgesia when mu (morphine) receptor blockers were pre-applied for both rats (Fleming et al., 1994) and planaria (Murugan and Persinger, 2014). Recent experiments by Buckner et al. (2015) indicated that one particular type of physiologically patterned field that is frequency modulated between 8 and 24 Hz involved T-type calcium channels.

Tessaro and Persinger (2013) showed that following mid-body section exposure to the same frequency-modulated patterned magnetic field that produced analgesia facilitated regeneration. The same pattern, when applied to mouse melanoma cells as well as other types of human and non-human malignant cells inhibited growth in culture (Karbowski et al., 2015). The growth of non-malignant or normal cells was not affected by these fields. Considering that this pattern induces both analgesia and suppression of growth of malignant cell lines, the possibility for a third alternative to classic treatments of cancers that would not produce iatrogenic illness and not affect normal cells became apparent. That the simultaneous pulsing of appropriately patterned magnetic fields and LED, specific wavelength light could produce unique phenomena that could exert profound effects upon biologically-relevant chemical pathways was shown by Karbowski et al. (2016). They showed that the simultaneous application of a blue wavelength and pulsed magnetic field with 1 ms point durations resulted in the maintenance of energy within melanoma cells that were re-released as photons 30–100 min after the cessation of the exposures. Considering these effects, we designed the following experiments to discern the specifics by which different wavelengths (blue, green, red) could synergistically enhance the facilitative adaptive effects of physiologically-patterned magnetic fields.

2. Methods

2.1. Planarian exposures

Dugesia tigrina planarian were removed from their housing populations, cut in half above the pharynx employing our standard procedure (Murugan et al., 2015) and placed in 1.5 mL Eppendorf tubes filled with 1 mL of fresh spring water. The planarian had been selected from the source to be visibly the same length, so any discernable variations as a function of treatment could be readily observed as well as measured. For the treatment sequence planaria (4 per dish) were transferred to a 60 mm plastic culture dish. The plates were placed within a darkened box. The magnetic field-LED device was placed directly upon the top of the covered dish by suspending it from the top of the box. The distance between the exposure device and the top of the plate was 3 cm. The application of the light or EMF was controlled using a switch mechanism which is a part of the hardware.

The physiologically-patterned stimulus sequence was generated by transforming a series of numbers from 0 through 256 to voltages between −5 and +5 V through a digital to analogue converter (DAC) where 127 = 0 V. The software allowed any series of numbers that could be theoretically derived or recorded from physiological conditions and transformed to this number range. The pattern selected for this experiment was a frequency-modulated configuration that has been called the "Thomas pattern" because of it potent effects in many settings across levels of discourse. The pattern is shown in Figure 1.

The software also allows the point duration of each of the series of integers from 0 to 256 to be to be programmable. We selected 3 ms because this point duration has produced the most significant effects upon a variety of biological and behavioral systems over the years (Fleming et al., 1994, Martin et al., 2004, Murugan and Persinger, 2014). The pattern was generated through the original Complex software created by Professor Stanley Koren. It was contained within a Lenovo computer that was connected to a

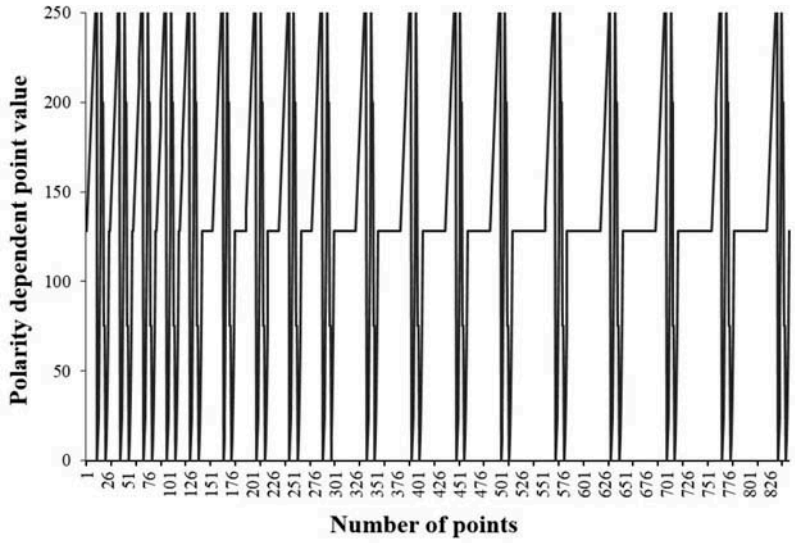

Figure 1. Shape of the frequency-modulated ("Thomas") pattern through which either the magnetic field, the colored light (either blue, green or red), or both the magnetic field and each of the colored lights were presented. The point durations for each of the 859 components (x-axis) between −5 and +5 V (y-axis) generated by the computer were all 3 ms.

DAC and then to the application unit where either the magnetic field only, the LEDs (either 470, 540 or 680 nm) only, or both the magnetic field component and the LED could be activated over the exposed planarian. As a result there were 8 treatments with 12 planarian per treatment (n = 96) completed in 3 separate experiments.

The duration of the exposures to the various treatments (magnetic field, LED only or field plus LED) was 1 h per day for 5 consecutive days. Daily images in order to discern length were recorded by a digital camera for each planarian. Each worm was placed in a glass Pyrex dish that was positioned over 1 × 1 cm grid paper. Image J was employed to quantify the daily lengths.

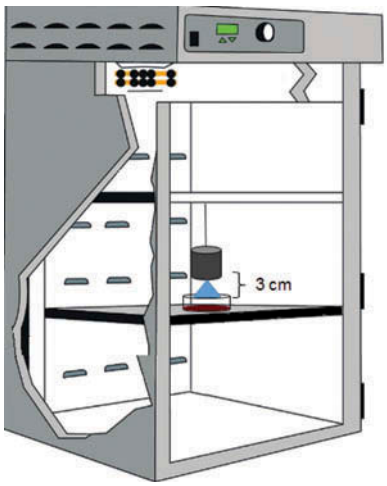

Figure 2. Schematic of light or magnetic field exposure setup for B16-Bl6 cell exposures.

2.2. Cells

B16-B6 melanoma cells were cultured onto 60 mm plates according to our standard procedures (Karbowski et al., 2012). The plates were exposed individually daily to light only, magnetic field only, or combination of light and magnetic fields for 1 h per day for 5 d under standard incubation conditions. Similar to the planarian exposures, the exposure device was suspended 3cm from the top of the culture dish. A schematic of the exposure conditions can be seen in Figure 2. For sham conditions, cultured plates of B16-Bl6 cells were placed in the same position underneath the magnetic field-LED device; however, no light or magnetic field were activated. Using 1.5 mL of PBS the cells were counted from a hematocytometer using our typical procedures. For each of the 8 treatment conditions there were 5 plates exposed on different days.

2.3. Equipment

A picture of one of the devices is shown in Figure 3. They were composed of 8 LEDs (of the same wavelength) arranged in a circle as described by Karbowski et al. (2016). The two nails in the center of the array

Figure 3. Any example of one of the arrays of 8 LEDs (separate device for the blue, green, and red wavelengths) surrounding the two poles from which the patterned magnetic field (Figure 1) was generated. The software was designed such that either the magnetic field only, the LEDs only, or both magnetic field and LEDs could be pulsed at the same time.

were extensions of a pair of solenoids that were modified reed relays (RadioShack 275-0232 SPST 5VDC, rated at 0.5 A at 125 VAC, with 20 mA nominal current) from which the magnetic field was generated.

According to a lux meter the flux density over the dish of cells or the planarian within the tissue plates containing either the cells or the planaria averaged 3000 Lux (range 2700 Lux to 3300 Lux). Magnetic field intensities as measured by power meters were between 26 and 40 mG (2.6–4.0 μT). We selected this intensity because it is the threshold for the value that converges with the Nernst component (about 26 mV) of the resting membrane potential that is independent of cation or anion gradients (Persinger and Lafrenie, 2014). When both the field and the light were activated there was no appreciable reduction in the flux densities of either the light or the magnetic field.

2.4. Statistical analyses

Means and standard deviations were obtained by SPSS-16 software for PCs. Because statistical significance between groups has been traditionally inferred by the absence of overlap between standard errors of the mean (SEMs) which is the standard deviation divided by the square root of the sample size we concluded that no overlap between standard deviation ranges would be sufficient criteria for statistical significance. In addition we were interested in robust effects rather than marginal statistical fluctuations. For estimated effect sizes (estimated Ω^2) separation of the means by more than two standard deviations was equivalent to explaining about 40% of the variance. However, for tradition, p-values were calculated.

3. Results

3.1. Planarian

The means and *standard deviations* for lengths of the dissected worms after 5 d of treatments are shown in Figure 4. Compared to the sham field exposed planarian the magnetic field produced a significant increase in planarian length, as demonstrated by one-way analysis of variance analyses ($p < 0.01$). Either exposures to only the blue light or the red light elicited a significant increase in planarian length compared to the sham controls ($p < 0.01$) but did not differ from the magnetic field conditions ($p = 0.994$ and $p = 0.577$, respectively). However, the blue light plus the magnetic field pattern ($p < 0.01$) and the red light plus the magnetic field pattern ($p < 0.01$) produced an additional increase in growth of the planarian. In contrast the planarian exposed to the green light or the green light plus the magnetic field did not differ from the control group ($p = 1.00$). In fact the group exposed to the magnetic field plus the green light displayed less growth than the group exposed to the magnetic field only. In other words the green light exposures cancelled the effect of the exposure to this physiologically-patterned (Thomas pulse) magnetic field.

These effects are more clearly demonstrated in Figure 5 which shows the relative changes in length compared to sham field reference groups. The green

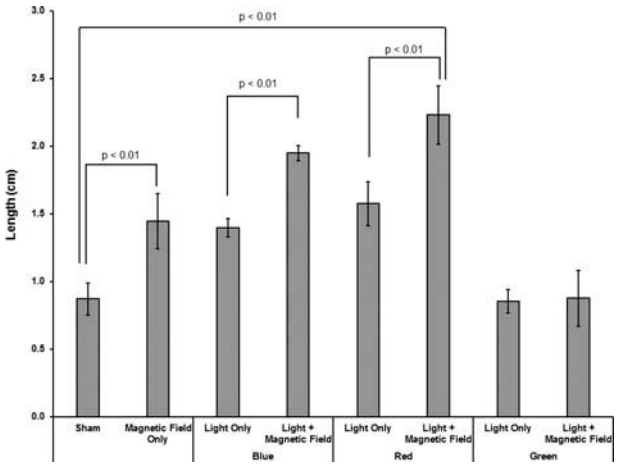

Figure 4. Length of planarian after 5 d of treatments that included exposure to no field or light, the physiologically-patterned magnetic field intensity only, the different LED wavelengths (blue, red, green) or to both the magnetic field pattern and each of the different colors. Vertical bars indicate *standard deviations*.

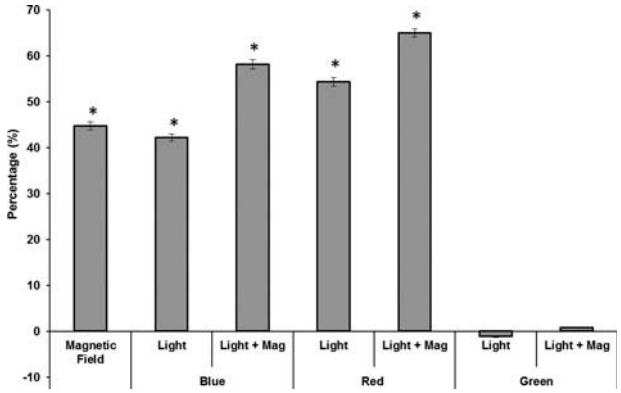

Figure 5. Percentage of increased length (growth) after 5 d of treatment compared to the reference group (sham field controls) after exposures to the physiologically-patterned magnetic field intensity only, the different LED wavelengths (blue, red, green) or to both the magnetic field pattern and each of the different colors. An asterisk indicates significant differences with a p-value <0.05.

light and magnetic field plus green light did not differ from the reference group. The group exposed to the Thomas pattern magnetic field only displayed a 40% increase in growth rate that was comparable to exposures to blue or red light only but not green light. The combination of the red light or blue light with the synchronized magnetic field was associated with an increase in growth length of 60%.

3.2. *Cells*

The results of the treatments upon the growth of the malignant mouse melanoma cells in culture are shown in Figure 6 which shows the means and standard deviations for numbers of cells per unit measurement volume. Cells exposed to this particular frequency-modulated magnetic field only displayed less growth. This was called the suppression rate. For example if there 83 cells in the treated dish and 127 in the reference dish, then 1- (83/127) would be 35% suppression.

The proportion was similar to that found in other studies for magnetic field only treatments with the Thomas pattern. One-way analysis of various showed that exposures only to blue light reduced the effect whereas the combination of blue light and the magnetic field enhanced the growth diminishment significantly more than exposure to red light only. In other words the blue and red light only conditions diminished cell growth compared to no treatment ($p < 0.01$ and $p < 0.01$, respectively) but were not as effective as the magnetic field only condition ($p < 0.01$) . The magnetic field plus red light condition did not differ appreciably from the magnetic field only condition ($p = 1.00$).

The cells exposed to green light only did not differ significantly from cells that were exposed to nothing (the controls). Combination of the magnetic field and the green light produced cell numbers that was comparable to the controls. In other words the combination of the green light and the magnetic field eliminated the suppressing effects of this patterned magnetic field.

4. Discussion

Photons, particularly within the visible range, have been considered the functional source of living systems.

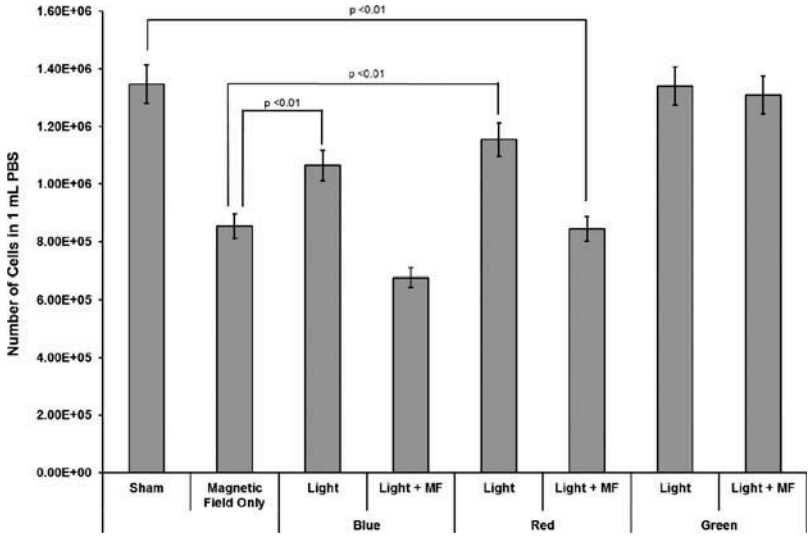

Figure 6. Number of melanoma cells in culture per unit volume after 5 d of treatment compared to the reference group (sham field controls) after exposures to the physiologically-patterned magnetic field intensity only, the different LED wavelengths (blue, red, green) or to both the magnetic field pattern and each of the different colors. Vertical bars indicated *standard deviations.*

Popp (1979) has argued that the photons from the sun have been represented or stored as virtual photons within the intricate structure of living matter since initial abiogenesis. They are intricately connected to the processes that define life. White light or "natural" light that is composed of various proportions of all of the increments of wavelengths within the visible spectrum might be expected to exhibit "averaging effects" in a manner similar to the simultaneous stimulation of all of the receptor subtypes for any chemical system such as opiates, dopamine, or serotonin when exposed to their common ligand. Only when one particular receptor subtype is activated or blocked compared to all others do very specific behaviors or states emerge.

The employment of LEDs with very specific wavelengths can be considered the analogue of targeting receptor subtypes. Our experimental results clearly indicated that the same frequency-modulated magnetic field that promotes analgesia in rats (Martin et al., 2004) or simulates this condition in planarian (Murugan and Persinger, 2014) facilitated the growth in regenerating planarian. This effect has been reported previously (Tessaro and Persinger, 2013). However in addition the exposure of only red or blue light simulated this growth effect. The combination of the red or the blue light and the magnetic field pattern increased this effect even more. From a pharmacological perspective the combination of the ultrahigh frequency (TeraHz) light and extremely low frequency frequency-modulated magnetic field could be considered a summation effect.

Such a "summation" effect would suggest that the two types of electromagnetic fields exhibited similar magnitude effects upon the biochemical processes that contribute to regeneration in planarian. According to the classic inference of magnetic energy where $E = [B^2 \cdot 2 \mu^{-1}] \cdot m^3$ where the latter is volume the energy from the 5 μT magnetic field within the volume of a planarian (10^{-9} m^3) would be ~10^{-4} J. On the other hand 3,000 Lux would have projected about 10 W m^{-2} upon the surface of the planarian. Assuming a flat worm of 3 10^{-6} m^2 the energy would be about 10^{-5} J/s.

For the energy values for the incident photons at specific wavelengths to converge with the energy within the volume of the planarian from the applied magnetic field, the photon effectiveness must occur in an area of 10^{-15} m^2. This would be equivalent to a linear distance of ~$3 \cdot 10^{-8}$ m or about 30 nm which is well within the range of the plasma cell membrane. The role of the plasma cell membrane in the generation of photons has been demonstrated experimentally by Dotta et al. (2011a) and calculated theoretically by Bokkon et al. (2010). Several other authors have indicated the importance of the membrane source for biophotons.

Applied photons can interact with membranes. In addition to the well-known rhodopisin relationship for photon energy transformations to signaling pathways, cephalopsins have been identified in brain tissue (Blackshaw and Snyder, 1999).That proteins embedded in membranes experimentally can enhance the photon-initiating features of pathways and ion channel conditions has been shown by many authors and is the bases of the new research area of optogenetics (Deisseroth, 2015). Mitsunaga et al., (2011) showed that selective *in vivo* infrared photoimmunotherapy could target specific membrane molecules. The effect was sufficient to induce shrinkage of tumors.

Whereas the red and blue wavelengths produced increases in planarian length that were comparable to that from exposure to the physiologically-patterned magnetic field, the melanoma cells showed less suppression of growth relative to the magnetic field treatment. Only the blue light in conjunction with the magnetic field presentation facilitated the suppression of this particular malignant cell's growth. The red light plus magnetic field exposures were not more effective than the magnetic field only. This differential pattern for melanoma cell proliferation compared to planarian regeneration suggests that different mechanisms may be involved.

The most challenging and intriguing result from the present study is the ineffectiveness of the green wavelength. In fact exposure of either the planarian or the melanoma cells to the green light or the green light at the same time as the magnetic field exposure *eliminated* the strong effects of the magnetic field exposure. According to Horne et al. (1991) human beings, for example, are particularly sensitive to green light. Nocturnal circulating melatonin levels are readily suppressed by this hue. The effect is not likely due to non-specific energies because the blue light and the red light which exhibit more and less energy photons were effective for the planarian. Other researchers have shown the efficacy of red and blue lights. For example Figueiro and Rea (2010) showed that both narrow band blue (470 nm) and red (625 nm) lights diminished the lower cortisol levels typically measured in the dark condition from human subjects. They did not employ green light.

There is another possibility. Green is a color that is ubiquitous in Nature. Some theorists argue that animal cells were derived from plant cells early in evolutionary history. Chlorophyll displays almost no absorption of green wavelengths. As a result the primary reflection is perceived as green. The trough of the curve is about 575 nm which is proximal to

the green wavelength employed in our studies. On the other hand 470 nm is highly absorbed by chlorophyll B while 680 nm is the range of highest absorption for chlorophyll A. If some recondite and quintessential process involving the 575 nm range was the antecedent for the evolutionary developments of biochemical pathways in living systems then interference with it by any exogenous wavelength may have been excluded from these pathways.

One mechanism could involve one of iron valence states, some of which are associated with green spectra. If the absorption of green wavelengths had not been controlled by exclusion, sensitive pathways such as the Fenton reaction would have allowed substantial variability of reactive oxygen species (ROS) substrates within cellular pathways. Another possibility is that because the green portion of the solar output contains the peak flux within the band, the consistent presence of this wavelength with little variability would have produced habituation very early in abiogenesis. From the results of the present experiments, this wavelength can even suppress the facilitative effects of physiologically-patterned magnetic fields.

5. Conclusion

The results of the present experiments demonstrated that both appropriately patterned magnetic fields and blue or red LED-generated wavelengths can comparably facilitate normal regeneration of planarian. The light was less effective than the magnetic field for suppression of malignant cell's abnormal proliferation. When the field and red or blue lights are pulsed together coherently the beneficial effects are enhanced. On the other hand the effects of exposure to green light did not differ from reference groups for cells or planarian. The simultaneous presentation of the magnetic field and the green light totally eliminated the facilitative effect of the magnetic field on planarian regeneration and the inhibitory effect for melanoma cell proliferation.

Declaration of Interest

The authors report no conflicts of interest. The authors alone are responsible for the content and writing of this article.

References

Baker-Price L., Persinger M. A. (2003). Intermittent burst-firing weak (1 microTesla) magnetic fields reduce psychometric depression in patients who sustained closed head injuries: A replication and electroencephalographic validation. *Perception Motor Skills* 96:965–974.

Bokkon, I., Salari, V., Tuszynski, J. A., Antal, I. (2010). Estimated numbers of biophotons involved in the visual perception of a single-object image: Biophoton intensity can be considerably higher inside cells than outside. *J. Photochem. Photobiol. B*, 100:160–166.

Blackshaw, S., Snyder, S. H. (1999). Encephalopsin: A Novel Mammalian Extraretinal Opsin Discretely Localized in the Brain. *J. Neurosci*. 19:3681–3690.

Buckner, C. A., Buckner, A. L., Koren, S. A., et al. (2015). Inhibition of cancer cell growth by exposure to a specific time-varying electromagnetic field involves T-type calcium channels. *PLoS One* 10:e0124136.

Choi, D. H, Lee, K. H., Moon, J. J., et al. (2012). Effect of 710 nm visible light irradiation on neurite outgrowth in primary rat cortical neurons following ischemic insult. *Biochem. Biophys. Res. Commun*. 422:274–279.

Deisseroth, K. (2015). Optogenetics: 10 years of microbial opsins in neuroscience. *Nat. Neurosci*. 18:1213–1225.

Dotta, B. T., Buckner, C. A., Cameron, D., et al. (2011a). Biophoton emissions from cell cultures: Biochemical evidence for the plasma membrane as the primary source. *Gen. Physiol. Biophys*. 30:301–309.

Dotta, B. T., Murugan, N. J., Karbowski, L. M., et al. (2014). Shifting the wavelengths of ultraweak photon emissions from dying melanoma cells: Their chemical enhancement and blocking are predicted by Cosic's theory of resonant recognition model for macromolecules. *Naturwissenschaften* 101:87–94.

Eells, J. T., Wong-Riley, M. T. T., VerHoeve, J., et al. (2004). Mitochondrial signal transduction in accelerated wound and retinal healing by near-infrared light therapy. *Mitochondrion* 4:559–567.

Fels, D. (2009). Cellular communication through light. *PloS One* 4(4): e5086.

Figueiro M. G., Rea M. S. (2010). The effects of red and blue lights on circadian variations in cortisol, alpha amylase, and melatonin. *Int. J. Endocrinol*. 2010:829351.

Fleming, J. L., Persinger, M. A., Koren, S. A. (1994). One second per four second magnetic pulses elevates nociceptive thresholds: Comparisons with opiate 30 receptor compounds in normal and seizure-induced brain damaged rats. *Electro Magnetobiol*. 13:67–75.

Horne, J. A., Donlon, J., Arendt, J. (1991). Green light attenuates melatonin output and sleepiness during sleep deprivation. *Sleep* 14:233–240.

Karbowski, L. M., Harribance, S. L., Buckner, C. A., et al. (2012). Digitized quantitative electroencephalographic patterns applied as magnetic fields inhibit melanoma cell proliferation in culture. *Neurosci. Lett*. 523:131–134.

Karbowski, L. M., Murugan, N. J., Koren, S. A., Persinger, M. A. (2015). Seeking the source of transience for a unique magnetic field pattern that completely dissolves cancer cells in vitro. *J. Biomed. Sci. Eng*. 8:531.

Karbowski, L. M., Murugan, Persinger, N. J., Karbowski, M. A. (2016). Experimental evidence that specific photon energies are "stored" in malignant cells for an hour: The synergism of weak magnetic field-LED wavelength pulses. *Biol. Med*. 8:1.

Kavaliers, M., Ossenkopp, K.-P. (1991). Opioid systems and magnetic field effects in the land snail, *Cepaeanemoralis*. *Biol. Bull*. 180:301–309.

Martin, L. J., Koren, S. A., Persinger, M. A. (2004). Thermal analgesic effects from weak, complex magnetic fields and pharmacological interactions. *Pharmacol. Biochem. Behav*. 78:217–227.

Masoumipoor, M., Behnam Jameie, S., Janzadeh, A., et al. (2013). Effects of 660 nm low level laser therapy on

neuropathic pain relief following chronic constriction injury in rat sciatic nerve. *Arch. Neurosci.* 1:76–81.

Mitsunaga, M., Ogawa, M., Kosaka, N., et al. (2011). Cancer cell-selective in vivo near infrared photoimmunotherapy targeting specific membrane molecules. *Nat. Med.* 17:1685–1691.

Murugan, N. J., Persinger, M. A. (2014). Comparisons of responses by planarian to micromolar to attomolar dosages of morphine or naloxone and/or weak pulsed magnetic fields: revealing receptor subtype affinities and non-specific effects. International *J. Radiat. Biol.* 90:833–840.

Murugan, N. J., Karbowski, L. M., Mekers, W. F. T., Persinger, M. A (2015). Group planarian sudden mortality: Is the threshold around global geomagnetic activity ≥K6? *Commun. Integrative Biol.* 8(6): e1095413.

Olcese J., Reuss, S. (1986). Magnetic field effects on pineal gland melatonin synthesis: comparative studies on albino and pigmented rodents. *Brain Res.* 369:365–368.

Oparin, A. I. (1965). *The Origins of Life*. New York: Dover Publications.

Persinger, M. A., Lafrenie, R. M. (2014). The cancer cell plasma membrane potentials as energetic equivalents to astrophysical properties. *Int. Lett. Chem. Phys. Astron.* 17:66–77.

Persinger, M. A. (2016). The biomass of the earth as the direct energy-mass equivalence from ≈3.5 billions of years of solar flux (in submission).

Popp, F.-A. (1979). Photon storage in biological systems. In: Popp F. A., Becker G., Konig H. L., Pescha W., (eds.), *Electromagnetic Bioinformation*. Munich: Urban and Schwarzenberg. pp. 123–149.

Tessaro, L. Persinger, M. A. (2013). Optimal durations for single exposures to a frequency-modulated magnetic field immediately after bisection in planarian predict final growth values. *Bioelectromagnetics*. 34(8):613–617.

Trushin, M. V. (2004). Light-mediated "conversation" among microorganisms. *Microbiol. Res.* 159:1–10

Van Wijk, R., Schamhart, D. H. J. (1988). Regulatory effects of low intensity photon emission. *Experientia* 44:586–593.

Wu, H.-P., Persinger, M. A. (2011). Increased mobility and stem-cell proliferation rate in Dugesia tigrina induced by 880 nm light emitting diode. *J. Photochem. Photobiol. B* 102:156–160.